



Research article

Effect of tillage, biochar, poultry manure and NPK 15-15-15 fertilizer, and their mixture on soil properties, growth and carrot (*Daucus carota* L.) yield under tropical conditions

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ABSTRACT

Tillage, biochar, poultry manure, NPK fertilizer and their combined application could improve soil quality, sustainability and carrot productivity. The effects of two tillage treatments: conventional tillage (CT) and reduced tillage (RT) each combined with 30 Mg ha⁻¹ biochar (B), 10 Mg ha⁻¹ poultry manure (PM), 300 kg ha⁻¹ NPK 15-15-15 fertilizer, 150 kg ha⁻¹ NPK 15-15-15 fertilizer +15 Mg ha⁻¹ biochar +5 Mg ha⁻¹ poultry manure and a control (no biochar/poultry manure/NPK fertilizer) on soil properties, growth and carrot yield were investigated. The research was carried out for two consecutive growing seasons (2018 and 2019) at Owo in the forest-savanna transition zone of Nigeria on a sandy loam. The experiment was laid out in a randomized complete block design in a factorial combination of ten treatments and replicated three times. Reduced tillage had relatively lower soil bulk density, penetration resistance, dispersion ratio and temperature, and had significantly higher ($p = 0.05$) soil aggregate stability, mean weight diameter, porosity and water content than conventional tillage and these resulted in higher soil pH, organic C, N, P, K, Ca and Mg, growth and fresh root yield of carrot compared with conventional tillage. Reduced tillage increased fresh carrot root yield by 2.3 Mg ha⁻¹ and 2.6 Mg ha⁻¹ for the first and second growing seasons, respectively, compared with conventional tillage, which corresponded to a 11.1% increment for both years. Application of biochar alone, poultry manure alone and complementary application of NPK fertilizer, biochar and poultry manure decreased soil bulk density, penetration resistance, dispersion ratio and temperature and increased soil water content, porosity, aggregate stability and mean weight diameter whereas NPK fertilizer did not improve these soil physical properties. Biochar alone, poultry manure alone, NPK fertilizer alone and combined application of NPK fertilizer, biochar and poultry manure increased soil total N, available P, and exchangeable K, Ca and Mg concentrations compared with the control. Application of biochar alone improved soil pH, OC, K, Ca and Mg better than the NPK fertilizer. Poultry manure improved soil pH, OC, N, K, Ca and Mg better than the NPK fertilizer. Combined application of NPK fertilizer, biochar and poultry manure at sub-optimal rates gave higher soil N, P, K, Ca and Mg concentrations, higher plant, number of leaves, root length, root diameter and fresh carrot root yield compared with NPK fertilizer or biochar or poultry manure alone. Compared with control, NPK fertilizer alone, biochar alone, poultry manure alone and mixture of NPK fertilizer, biochar and poultry manure increased fresh carrot root yield by 43, 24, 46 and 76%, respectively. Reduced tillage in combination with NPK fertilizer, biochar and poultry manure gave the highest fresh carrot root yield. The results indicated that reduced tillage in combination with NPK fertilizer, biochar and poultry manure prove to be an effective and sustainable management strategy for improving soil quality and carrot yield than conventional tillage in combination with NPK fertilizer, biochar and poultry manure.

1. Introduction

Carrot (*Daucus carota* L.) is a cool season crop which belongs to the Apiaceae family. It is one of the major vegetable crops cultivated throughout the world for its edible roots. It is good for the eyes health due

to the high content of carotenoids, a class of phytochemicals precursors of vitamin A and therefore, help to reduce the risk of vitamin A deficiency (Kopsell and Kopsell, 2006). It also contains appreciable amounts of nutrients such as protein, carbohydrates, fiber, thiamine, riboflavin, iron, calcium, phosphorus and vitamins C, K, B1, B2, B6 (Pant and Manandhar,

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2007; Arscott and Tanumihardjo, 2010; Sharma et al., 2012). It is eaten raw (salad), shredded, boiled or cooked as stews, soups, curries, etc. and also used for the preparation of pickles, jam, and sweet dishes. Besides food value, different parts of carrot can be used for different medicinal purposes due to a wide range of reported pharmacological effects (Pant and Manandhar, 2007; Rossi et al., 2007; Tavares et al., 2008).

Carrot production can be a beneficial enterprise for small-scale, resource-poor farmers because it is a short duration crop and higher yields can be obtained per unit area (Ahmad et al., 2005). According to FAO (1999), carrot yield per unit area in most developing countries, is still below the recommended world average. The main reason for low yields is depleted soil fertility and poor soil management practices, which reduce productivity and sustainability of carrot crop. Generally, most carrot growers use inorganic fertilizers to realize higher growth and yields (Dauda et al., 2008). The use of synthetic fertilizers as a source of nutrient has however, been associated with high soil acidity, human health problems and soil degradation. In addition, the exorbitant costs of inorganic fertilizers have made them generally unaffordable to most resource-poor, small-scale growers. It is, therefore, necessary to find alternative solutions. Under such conditions, application of organic materials, such as biochar, could increase soil fertility and crop production by minimizing the leaching of nutrients or by supplying the nutrients to the plants.

Biochar is a carbon-rich material produced during pyrolysis process that is a thermochemical decomposition of biomass with a temperature about ≤ 700 °C in the absence or limited supply of oxygen (Lehmann and Joseph, 2015). It has higher pore space, negative surface charge and surface area (Lehmann and Joseph, 2015), higher water holding capacity, reduced soil bulk density (Adekiya et al., 2019) and reduced nutrient losses, thereby offering the possibility of improving yields (Adekiya et al., 2019, 2020). Nguyen et al. (2017) reported that through pyrolysis process, pure organic waste/material is converted into a valuable product with distinctive physicochemical properties that can contribute to good soil environment for better crop performance. According to Domingues et al. (2017), pyrolysis leads to high aromaticity of carbon, which makes biochar more recalcitrant to biodegradation. Hence, biochar-treated soils have high carbon residence time compared with non-treated soils. Furthermore, biochar was reported to have high cation exchange capacity, with diverse acidic and basic functional groups, which helps to adsorb nutrients on its surface and better synchronize their release with plant uptake (Mandal et al., 2016; Esfandbod et al., 2017). Application of biochar could improve soil physical, chemical and biological properties, addition to affecting soil carbon and nitrogen cycles (Sadaf et al., 2017). Biochar contains macronutrients and increases soil nutrient availability, thus improving plant growth and grain yield.

Poultry manure is another amendment that has received much attention for its potential to improve similar soil quality characteristics. Poultry manure is a key resource in increasing and maintaining soil fertility, by providing nutrients, increasing soil organic matter, cation exchange capacity (CEC) and pH (acid soils), improving soil physical properties like water-holding capacity (WHC) and reducing soil erosion (Adeleye et al., 2010). Poultry manure is well known for its soil quality benefits including decreasing soil bulk density and increasing water holding capacity, nutrient input and retention, and biodiversity, which is mostly in response to increased soil organic matter (Adekiya et al., 2019, 2020). Organic amendments, particularly poultry manure, can thus replace or supplement mineral fertilizers and lime in reversing soil degradation.

In Nigeria, large-scale carrot production is mostly under conventional tillage, which leads to loss of organic matter, decline in soil fertility, destruction of soil structure, over-drying of topsoil, impaired nutrient cycling, water erosion, reduction of the population of geobiont etc (Lal, 1993; Briones and Schmidt, 2017). More importantly, conventional tillage increases operational cost while disrupting the structure and other important properties of the soil (Shahzad et al., 2017). Thus, adoption of reduced tillage could save cultivation costs, allow crop residues to act as

an insulator, reduce soil temperature fluctuation, build up soil organic matter, conserve soil moisture while improving long-term sustainability of the soil for crop growth (Schwab et al., 2002; West and Post, 2002; Gürsoy et al., 2010; Salem et al., 2015). Most previous studies on soil properties, growth and crop yields have evaluated the benefits of biochar alone and not the combination of biochar and other amendments. Combining biochar with other amendments could improve the effectiveness of biochar for improving soil properties. Also, studies of biochar in combination with other amendments (e.g. animal manure or inorganic fertilizers), field management (e.g., tillage) are lacking. However, this information is needed to draw conclusions and make practical recommendations for large-scale use of biochar for different management and climatic scenarios. To this end, the objective of this study was to evaluate the effects of conventional tillage and reduced tillage systems and biochar, poultry manure, NPK 15-15-15 fertilizer, and their combination on soil properties, growth and yield of carrot in southwestern Nigeria.

2. Materials and methods

2.1. Study site

Field experiments were conducted at the research field of the Department of Crop, Soil and Pest Management Technology, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria (latitude $7^{\circ}13'29.0''N$ - $7^{\circ}13'30.9''N$ and longitude $5^{\circ}32'52.3''E$ - $5^{\circ}32'54.2''E$, with elevation varying from 314 to 320 m above sea level (Figure 1). The experimental field used is characterized by a forest-savanna transition zone climate. The average long-term annual precipitation for the previous 30 years was 1421 mm, and mean annual temperatures was 32 °C. The soil at Owo belongs to the broad group Alfisol classified as Oxic Tropudalf (Soil Survey Staff, 2014) or Luvisol (IUSS Working Group WRB, 2015) of the basement complex, derived from quartz, gneiss and schist (Adepetu et al., 1979), and locally classified as Okemesi Series (Smyth and Montgomery, 1962). The soil is composed of sand, silt, and clay content of 62, 26, and 12%, respectively. The soil is a sandy loam, with pH of 5.5, organic carbon of 1.35%, total N of 0.16%, available P of 8.0 mg kg⁻¹, exchangeable K of 0.12 cmol kg⁻¹, exchangeable Ca of 1.5 cmol kg⁻¹, and exchangeable Mg of 0.32 cmol kg⁻¹ (Table 1).

2.2. Field experiments and treatments

The experiment each year consisted of 2×5 factorial combinations of two tillage treatments and five fertilizer treatments. The tillage treatments were conventional tillage (CT): ploughing to a depth of 30 cm with tractor mounted disc plough, followed by two passes with tractor-mounted disc harrow to a depth of 20 cm, and raised bed preparation with a hoe and a rake and reduced tillage (RT): ploughing to a depth of 20 cm with tractor mounted disc plough, followed by one pass with tractor-mounted disc harrow to a depth of 15 cm, and raised bed preparation with a hoe and a rake. The dimensions of the raised bed plots were 0.2 m high x 4 m long x 1 m wide. The fertilizer treatments were control (no fertilizer/biochar/poultry manure), NPK-15-15-15 fertilizer at 300 kg ha⁻¹, biochar at 30 Mg ha⁻¹, poultry manure at 10 Mg ha⁻¹ and combined application of NPK 15-15-15 fertilizer at 150 kg ha⁻¹ + biochar at 15 Mg ha⁻¹ + poultry manure at 5 Mg ha⁻¹. This study used biochar application rate within the recommended levels (5–50 Mg ha⁻¹) by the International Biochar Initiative (Jirka and Tomlinson, 2015). The ten treatments were factorially arranged in a randomized complete block design and replicated three times. The same exact position and layout of plots and treatments were used for the experiment in 2018 and 2019.

2.3. Crop establishment and management practices

Carrot seeds, cv 'Touchon' sourced from Agricultural Input Supply Company, Ondo State, Nigeria were sown on raised beds/plots on 20 April 2018 and 2 May 2019 for the first and second trials, respectively, by

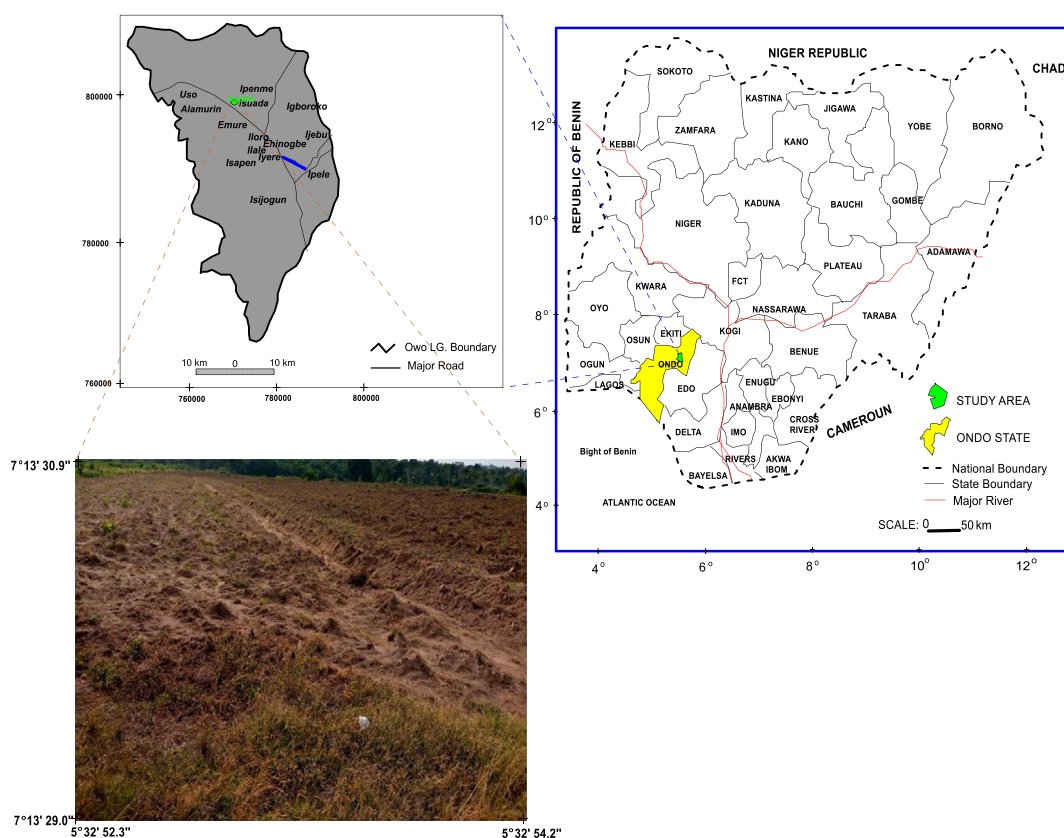


Figure 1. Location map of the study area on map of Nigeria.

Table 1. Soil physical and chemical properties of the site prior to experimentation in 2018.

Property	Value
Sand (%)	62 ± 1.4
Silt (%)	26 ± 0.08
Clay (%)	12 ± 0.06
Textural class	Sandy loam
Bulk density (Mg m^{-3})	1.59 ± 0.02
pH (water)	5.5 ± 0.05
Organic carbon (%)	1.35 ± 0.02
Total N (%)	0.16 ± 0.01
Available P (mg kg^{-1})	8.0 ± 0.03
Exchangeable K (cmol kg^{-1})	0.12 ± 0.01
Exchangeable Ca (cmol kg^{-1})	1.5 ± 0.05
Exchangeable Mg (cmol kg^{-1})	0.32 ± 0.02

drilling to a depth of 1 cm at 25 cm between rows. Before sowing, the carrot seeds were treated with a seed-dressing fungicide (Apron plus 50 DS) to prevent seed-borne or soil-borne pathogens. The beds were covered with straw to prevent excessive heat and retain seed on beds. The straw was removed at sixth day after sowing. Thinning was done at 3 weeks after emergence of the crop to an intra-row spacing of 10 cm between plants, giving a plant population of 160 plants per plot. Biochar and poultry manure were applied prior to carrot planting, thoroughly worked into the soil with a hoe at 10 cm depth. The NPK fertilizer was split applied: half the rate was applied at 3 weeks after sowing and other half at 6 weeks after sowing. The NPK fertilizer was banded 5 cm deep and 10 cm to the side of the rows during the application. Weeding by hand pulling was done at 3 weeks interval till harvest to ensure clean plots. No irrigation was carried out to the crops/plots during the

experiment; the carrot crop was raised under rainfed system. To protect the carrot from direct sunlight which could cause undesirable green colouration, earthing up of carrot shoulders was done frequently.

2.4. Biochar and poultry manure preparation

Biochar used in the experiment was obtained from a nearby industrial charcoal producer at Owo, Ondo State, Nigeria who makes use of hardwood such as *Parkia biglosa*, *Khaya senegalensis*, *Prosopis africana* and *Terminalia glaucescens* in traditional kilns to produce charcoal for domestic use. The temperature inside the kiln was monitored with a thermocouple and had an average temperature of 580 °C for 24 h of carbonizing. The biochar was ground and sieved through a 2 mm sieve before application.

The poultry manure (PM) was obtained from the poultry unit of the Teaching and Research Farm of Rufus Giwa Polytechnic, Owo, Ondo State. The poultry manure was composted for 3 weeks to allow for mineralization.

2.5. Soil, biochar and poultry manure analysis

In 2018, prior to the commencement of the experiment, the top 0–15 cm depth of the soil profile was sampled following a random sampling design at various points across the entire experimental field using a soil auger after which a composite sample was derived for physical and chemical analysis. At harvest in 2019 (second crop), another soil samples were collected randomly at 0–15 cm depth from the centre of each plot at five sites per plot for routine chemical analysis. The soil, biochar and poultry manure samples were bulked, air dried, ground and sieved through a 2-mm sieve and their nutrient composition were determined following standard procedures (Carter and Gregorich, 2007). Particle size analysis was done using a hydrometer method. Textural class was

determined using textural triangle. The soil pH was measured in a soil-water (1:2, v:v) suspension using a digital electronic pH meter. Organic carbon was determined by the Walkley and Black procedure using the dichromate wet oxidation method. Total N was determined by the micro-Kjeldahl digestion method. Available P was determined calorimetrically using a spectrophotometer. Exchangeable K, Ca and Mg from soil, biochar and poultry manure were extracted using 1 M ammonium acetate. Thereafter, K was determined using a flame photometer, and Ca and Mg were determined using an atomic absorption spectrophotometer (AAS).

2.6. Determination of soil physical properties

One month after sowing carrot and application of soil amendments and fertilizer, some selected soil physical properties were determined on plots basis. Measurements were taken monthly for three successive months in each year. Five core samplers (4 cm in diameter, 15 cm high) in each occasion were used to collect soil samples from 0–15 cm depth at about 10 cm from carrot crop. The soil samples were used for the evaluation of bulk density and gravimetric water content after drying in an oven at 100 °C for 24 h. Total porosity was calculated from the values of bulk density and particle density of 2.65 Mg m⁻³. Soil temperature was determined at 15:00 h with a soil thermometer inserted to 15 cm depth. Five readings were made per plot at each sampling time.

Soil penetration resistance (PR) was measured by using a portable hardness tester (Soil Hardness Meter, Yamanaka type, Daiki Rika Kogyo Co., Japan). Modified fast-wetting in water, as described by Le Bissonnais (2016), was used to measure the aggregate stability of 2-mm air-dried aggregates (35 g). A 4 cm amplitude was applied for 5 min vertical movement to a nest of sieves (>2000, 1000–2000, 500–1000, 250–500, 250–106, <106 mm) immersed in a container of tap water (101 mS/cm). The material that remained after wet-shaking in each sieve was carefully removed, and the mean weight diameter (MWD) of the aggregate size was calculated using

$$MWD = \sum_{i=1}^n (x_i w_i), \quad (1)$$

where n is the number of sieves, and x and w are diameter and weight, respectively.

Dispersion ratio was done by determining the amounts of silt and clay in calgon-dispersed as well as water-dispersed samples using the Bouyoucos hydrometer method of particle size analysis described by Gee and Or (2002). Dispersion ratio was determined as a measure of aggregate stability using the following formula:

$$\text{Dispersion ratio} = \frac{\% \text{ silt} + \text{clay (H}_2\text{O}_2)}{\% \text{ silt} + \text{clay (calgon)}} \times 100 \quad (2)$$

2.7. Determination of growth and yield parameters of carrot

Ten plants were randomly selected per plot from the middle rows and tagged for data collection. Height of carrot plants was measured using a ruler on a fortnight basis, and the measurement for each plant was taken from the ground level to the top of the apex of the longest leaf. On the same plants, number of leaves per plant of fully expanded leaves were also determined by counting. At crop maturity, 10 carrot plants were randomly selected to determine the root length, core diameter of carrot roots, and yield. Roots of sampled plants were detached from shoots and the fresh root weight was determined using a weighing scale balance. Obtained weights were recorded in kg plot⁻¹ and later converted to Mg ha⁻¹. Root length was determined using a ruler at 0.5 cm from the top of the shoulder to the end of the root tip and core diameter of carrot roots were also measured at 0.5 cm from the top of the shoulder using a ruler.

2.8. Statistical analysis

Data collected from each experiment were subjected to analysis of variance (ANOVA) using the Genstat for Windows 21st Edition (VSN

International, 2020) to determine the effects of treatments on soil physical and chemical properties, growth and yield of carrot. The standard error of difference between means (SED) was used to compare the treatment means. Mention of statistical significance refers to $p = 0.05$, unless stated otherwise.

3. Results

3.1. Initial soil fertility status and analysis of biochar and poultry manure

The soil was sandy loam in texture, slightly acidic, and had high bulk density, low organic carbon (OC), total N, available P, exchangeable K, exchangeable Ca and Mg (Table 1) according to the critical values of 3% OM, 0.20% N, 10 mg kg⁻¹ available P, 0.16–0.20 cmol kg⁻¹ exchangeable K, 2 cmol kg⁻¹ exchangeable Ca and 0.40 cmol kg⁻¹ exchangeable Mg recommended for crop production in ecological zones of Nigeria (Akinrinde and Obigbesan, 2000). The biochar used in the experiment was alkaline, while poultry manure used was slightly acidic (Table 2). Biochar was high in organic C, K, Ca, and Mg, and had a high C:N ratio compared with poultry manure, but poultry manure had higher concentrations of N, P, and micronutrients compared with biochar (Table 2).

3.2. Effect of year, tillage, biochar, poultry manure and NPK 15-15-15 fertilizer, and their combination on soil physical properties

The soil bulk density, porosity, water content, temperature, penetration resistance, aggregate stability, dispersion ratio and mean weight diameter as affected by year, tillage, biochar, poultry manure and NPK 15-15-15 fertilizer, and their combination are presented in Table 3. In both years (2018 and 2019), soil under reduced tillage (RT) treatment had significantly lower ($p = 0.05$) bulk density, temperature, penetration resistance and dispersion ratio, and significantly higher ($p = 0.05$) soil total porosity, water content, aggregate stability and mean weight diameter compared with conventional tillage (CT) treatment (Table 3). Compared with tillage alone (control), application of biochar alone, poultry manure alone and mixture of NPK fertilizer, biochar and poultry manure improved soil physical conditions as indicated by reduced soil bulk density, temperature, penetration resistance and dispersion ratio, and increased soil porosity, water content, aggregate stability and mean weight diameter. The decreases/increases on soil bulk density, porosity, water content, temperature, penetration resistance, dispersion ratio, aggregate stability and mean weight diameter were often significant ($p = 0.05$) (Table 3). Application of NPK fertilizer did not improve any of the soil physical properties (soil bulk density, porosity, water content, temperature, penetration resistance, aggregate stability, dispersion ratio and mean weight diameter).

Table 2. Chemical composition of biochar and poultry manure used in the experiment.

Property	Biochar	Poultry manure
Bulk density (Mg m ⁻³)	0.32	ND
Specific surface area (m ² g ⁻¹)	2.83	ND
pH (water)	8.32	6.85
Ash content (%)	0.48	12.2
Organic C (%)	58.3	22.5
Total N (%)	0.65	2.88
C:N	89.7	7.8
Available P (%)	0.73	1.30
Exchangeable K (cmol kg ⁻¹)	1.95	1.46
Exchangeable Ca (cmol kg ⁻¹)	2.61	1.52
Exchangeable Mg (cmol kg ⁻¹)	1.14	0.61
Electrical conductivity (dS m ⁻¹)	2.60	0.95

Table 3. Effect of year, tillage, biochar, poultry manure and NPK 15-15-15 fertilizer, and their combination on soil physical properties.

Year	Tillage	Fertilizer	Bulk density (Mg m ⁻³)	Porosity (%)	Water content (g kg ⁻¹)	Temperature (°C)	PR (kg cm ²)	Aggregate stability (%)	DR (%)	MWD (mm)
2018	CT		1.52	42.6	100	33.4	13.8	3.0	0.76	1.2
	CT	300 kg ha ⁻¹ NPK	1.51	43.0	101	33.3	13.5	3.1	0.76	1.2
	CT	30 Mg ha ⁻¹ B	1.23	53.6	129	27.1	7.1	4.8	0.61	1.6
	CT	10 Mg ha ⁻¹ PM	1.20	54.7	122	28.9	8.6	3.7	0.67	1.4
	CT	150 kg ha ⁻¹ NPK +15 Mg ha ⁻¹ B + 5 Mg ha ⁻¹ PM	1.07	59.6	149	30.7	6.2	6.2	0.56	1.8
	RT		1.36	48.7	112	33.0	14.1	3.4	0.72	1.2
	RT	300 kg ha ⁻¹ NPK	1.34	49.4	113	33.1	14.2	3.5	0.72	1.2
	RT	30 Mg ha ⁻¹ B	1.06	60.0	142	27.0	8.9	5.9	0.56	1.7
	RT	10 Mg ha ⁻¹ PM	1.04	60.8	135	28.7	7.7	4.9	0.61	1.6
	RT	150 kg ha ⁻¹ NPK +15 Mg ha ⁻¹ B + 5 Mg ha ⁻¹ PM	0.93	64.9	163	30.5	5.8	7.4	0.51	1.9
2019	CT		1.54	41.9	115	32.6	14.2	3.0	0.78	1.2
	CT	300 kg ha ⁻¹ NPK	1.53	42.3	114	32.5	14.1	3.0	0.78	1.2
	CT	30 Mg ha ⁻¹ B	1.21	54.3	143	26.4	6.3	5.0	0.60	1.7
	CT	10 Mg ha ⁻¹ PM	1.19	55.1	138	28.2	7.2	3.9	0.65	1.6
	CT	150 kg ha ⁻¹ NPK +15 Mg ha ⁻¹ B + 5 Mg ha ⁻¹ PM	1.05	60.4	154	30.0	4.4	6.3	0.59	1.8
	RT		1.37	48.3	127	32.4	13.8	3.3	0.73	1.2
	RT	300 kg ha ⁻¹ NPK	1.35	49.1	125	32.3	13.9	3.3	0.73	1.2
	RT	30 Mg ha ⁻¹ B	1.04	60.8	156	26.1	5.4	6.1	0.52	1.7
	RT	10 Mg ha ⁻¹ PM	1.03	61.1	140	28.0	6.1	5.0	0.58	1.7
	RT	150 kg ha ⁻¹ NPK +15 Mg ha ⁻¹ B + 5 Mg ha ⁻¹ PM	0.91	65.7	178	29.8	4.0	7.5	0.45	1.9
	SE		0.05	1.74	4.67	0.56	0.87	0.34	0.02	0.06
Year (Y)			0.043	0.031	0.000	0.000	0.000	0.000	0.021	0.000
Tillage (T)			0.000	0.000	0.000	0.016	0.024	0.000	0.000	0.000
Fertilizer (F)			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y x T			0.701	0.901	0.031	1.000	0.002	0.008	0.043	0.006
Y x F			0.068	0.890	0.015	0.997	0.000	0.000	0.016	0.000
T x F			0.025	0.041	0.000	0.999	0.017	0.000	0.003	0.000
Y x T x F			0.994	1.000	0.000	0.993	0.029	0.860	0.611	0.018

CT = Conventional tillage; RT = Reduced tillage; B = Biochar; PM = Poultry manure; NPK 15-15-15 fertilizer; PR = Penetration resistance; DR = Dispersion ratio; MWD = Mean weight diameter.

When studied as individual factors, year (Y), tillage (T) and fertilizer (F) (application of NPK fertilizer, biochar and poultry manure) significantly ($p = 0.05$) influenced soil physical properties – bulk density, porosity, water content, temperature, penetration resistance, aggregate stability and mean weight diameter. The interactive effect of $Y \times T$ and $Y \times F$ were significant for water content, penetration resistance, aggregate stability, dispersion ratio and mean weight diameter, but not significant for bulk density, porosity and temperature. The interactive effect of $T \times F$ was significant for all soil physical properties considered, except soil temperature. When all the three factors ($Y \times T \times F$) were considered together, interactions were significant for soil water content, penetration resistance and mean weight diameter. However, interactions were not significant for soil bulk density, porosity, temperature, aggregate stability and dispersion ratio.

3.3. Effect of tillage, biochar, poultry manure and NPK 15-15-15 fertilizer, and their combination on soil chemical properties in 2019 after crop harvest

Soil pH, OC, total N, available P, exchangeable K, Ca and Mg were significantly higher ($p = 0.05$) in the reduced tillage treatment than the conventional tillage treatment at the 0–15 cm depth after 2 years of cultivation (Table 4). Therefore, conventional tillage reduced soil fertility compared with reduced tillage. Application of NPK fertilizer alone increased N, P K, Ca and Mg compared with the control, but did not increase soil organic C, while soil pH was reduced. Irrespective of tillage method, application of poultry manure alone improved soil pH, OC, N, K, Ca and Mg better than the NPK fertilizer alone. Application of biochar alone improved soil pH, OC, K, Ca and Mg better than the NPK fertilizer alone. Application of poultry manure alone increased soil N, P, Ca and Mg better than the biochar alone, but biochar alone increased soil pH and OC better than the poultry manure alone. Irrespective of tillage method, mixture application of NPK fertilizer, biochar and poultry manure significantly increased ($p = 0.05$) soil total N, available P, exchangeable K, Ca and Mg concentrations after 2 years of cultivation compared with biochar, poultry manure or NPK fertilizer alone (Table 4).

When considered as single factors, tillage (T) and fertilizer (F) significantly influenced soil chemical properties (soil pH, OC, N, K, Ca and Mg). The interactive effect of $T \times F$ were significant for soil OC, N, K, Ca and Mg, but interactions were not significant for soil pH and P.

3.4. Effect of year, tillage, biochar, poultry manure and NPK-15-15-15 fertilizer, and their combination on growth parameters and fresh root yield of carrot

Carrot grown under reduced tillage had higher plant, number of leaves, root length, root diameter and fresh root yield, and these were statistically different from conventional tillage treatment (Table 5). Reduced tillage increased fresh carrot root yield by 2.3 Mg ha^{-1} and 2.6 Mg ha^{-1} for the first and second growing seasons, respectively, compared with conventional tillage, which corresponded to a 11.1% increment for both years (Table 5).

Irrespective of tillage method, application of NPK fertilizer alone, biochar alone, poultry manure alone and mixture of NPK fertilizer, biochar and poultry manure significantly increased ($p = 0.05$) plant height, number of leaves, root length, root diameter and fresh root yield of carrot compared with the control (Table 5). Application of NPK fertilizer alone and poultry manure alone had similar values of plant height, number of leaves, root diameter and fresh root yield of carrot. However, the root length under application of poultry manure alone was significantly higher ($p = 0.05$) than NPK fertilizer alone. The mixture application of NPK fertilizer, biochar and poultry manure significantly increased growth parameters and fresh root yield compared with other tillage-fertilizer treatments. The control produced the lowest values of growth and yield parameters compared with other treatments. Growth and yield parameters under biochar alone were significantly lower ($p = 0.05$) compared with NPK fertilizer alone, poultry manure alone and mixture application of NPK fertilizer, biochar and poultry manure. The mean fresh root yield of carrot for the control, application of NPK fertilizer alone, poultry manure alone and mixture application of NPK fertilizer, biochar and poultry manure were 23.4, 33.4, 29.0, 34.1 and 41.3 Mg ha^{-1} , respectively. Averaged over 2 years, application of NPK fertilizer, biochar, poultry manure and mixture application of NPK fertilizer, biochar and poultry manure increased fresh root yield of carrot by 43, 24, 46 and 76%, respectively. Mixture of NPK fertilizer, biochar and poultry manure with reduced tillage gave the highest value of carrot root yield and it was significantly higher when compared with combination of NPK fertilizer alone with RT, poultry manure alone with RT and biochar alone with RT (Table 5).

Table 4. Effect of tillage, biochar, poultry manure and NPK 15-15-15 fertilizer, and their combination on soil chemical properties (0–15 cm depth) in 2019 after crop harvest.

Tillage	Fertilizer	pH (water)	OC (%)	Total N (%)	Available P (mg kg ⁻¹)	Exchangeable K (cmol kg ⁻¹)	Exchangeable Ca (cmol kg ⁻¹)	Exchangeable Mg (cmol kg ⁻¹)
CT		5.0	1.11	0.12	6.6	0.09	1.2	0.26
CT	300 kg ha ⁻¹ NPK	4.6	1.12	0.15	8.2	0.11	1.4	0.32
CT	30 Mg ha ⁻¹ B	5.5	1.97	0.14	9.3	0.14	2.0	0.38
CT	10 Mg ha ⁻¹ PM	5.0	1.56	0.17	10.8	0.15	2.3	0.50
CT	150 kg ha ⁻¹ NPK +15 Mg ha ⁻¹ B + 5 Mg ha ⁻¹ PM	5.3	1.77	0.20	12.9	0.18	2.5	0.66
RT		5.5	1.22	0.14	7.2	0.10	1.4	0.29
RT	300 kg ha ⁻¹ NPK	5.3	1.24	0.17	9.8	0.13	1.7	0.36
RT	30 Mg ha ⁻¹ B	6.1	2.13	0.15	10.9	0.16	2.3	0.42
RT	10 Mg ha ⁻¹ PM	5.7	1.74	0.19	12.4	0.17	2.5	0.56
RT	150 kg ha ⁻¹ NPK +15 Mg ha ⁻¹ B + 5 Mg ha ⁻¹ PM	5.9	1.94	0.22	14.6	0.21	2.8	0.73
	SE	0.14	0.12	0.009	0.81	0.01	0.17	0.05
Tillage (T)		0.000	0.000	0.000	0.000	0.000	0.000	0.001
Fertilizer (F)		0.000	0.000	0.000	0.000	0.000	0.000	0.000
T x F		0.989	0.022	0.032	0.314	0.035	0.0042	0.038

CT = Conventional tillage; RT = Reduced tillage; B = Biochar; PM = Poultry manure; NPK 15-15-15 fertilizer.

Table 5. Effect of year, tillage, biochar, poultry manure and NPK 15-15-15 fertilizer, and their combination on carrot plant height, number of leaves, root diameter, root length, and fresh root yield.

Year	Tillage	Fertilizer	Plant height (cm)	Number of leaves per plant	Root length (cm)	Root diameter (cm)	Fresh root yield (Mg ha ⁻¹)
2018	CT		20.1	7.4	13.0	1.02	22.5
	CT	300 kg ha ⁻¹ NPK	28.2	10.7	13.2	1.29	32.2
	CT	30 Mg ha ⁻¹ B	24.1	8.4	17.8	1.14	27.6
	CT	10 Mg ha ⁻¹ PM	27.9	10.5	18.2	1.31	32.4
	CT	150 kg ha ⁻¹ NPK +15 Mg ha ⁻¹ B + 5 Mg ha ⁻¹ PM	30.9	11.8	18.5	1.67	39.5
	RT		20.5	8.0	15.4	1.07	24.8
	RT	300 kg ha ⁻¹ NPK	28.4	11.7	15.7	1.46	34.9
	RT	30 Mg ha ⁻¹ B	24.3	10.5	19.8	1.28	30.1
	RT	10 Mg ha ⁻¹ PM	28.1	11.6	20.0	1.49	35.4
	RT	150 kg ha ⁻¹ NPK +15 Mg ha ⁻¹ B + 5 Mg ha ⁻¹ PM	31.6	12.9	20.5	1.85	42.3
2019	CT		19.5	7.1	12.8	1.01	21.9
	CT	300 kg ha ⁻¹ NPK	28.0	10.5	13.0	1.27	31.8
	CT	30 Mg ha ⁻¹ B	24.8	8.6	18.4	1.16	27.8
	CT	10 Mg ha ⁻¹ PM	28.5	10.7	18.8	1.31	32.6
	CT	150 kg ha ⁻¹ NPK +15 Mg ha ⁻¹ B + 5 Mg ha ⁻¹ PM	32.0	12.0	19.1	1.69	39.8
	RT		19.9	7.8	15.0	1.06	24.5
	RT	300 kg ha ⁻¹ NPK	28.1	11.5	15.3	1.44	34.6
	RT	30 Mg ha ⁻¹ B	25.1	10.7	20.4	1.30	30.4
	RT	10 Mg ha ⁻¹ PM	28.3	11.8	20.6	1.46	35.8
	RT	150 kg ha ⁻¹ NPK +15 Mg ha ⁻¹ B + 5 Mg ha ⁻¹ PM	32.4	13.1	21.0	1.87	43.7
	SE		0.91	0.41	0.64	0.05	1.39
Year (Y)			0.139	0.817	0.378	0.274	0.701
Tillage (T)			0.020	0.000	0.000	0.000	0.000
Fertilizer (F)			0.000	0.000	0.000	0.000	0.000
Y x T			0.990	0.939	0.847	0.948	0.565
Y x F			0.150	0.627	0.594	0.087	0.674
T x F			0.961	0.015	0.023	0.000	0.038
Y x T x F			0.961	1.000	1.000	1.000	0.984

CT = Conventional tillage; RT = Reduced tillage; B = Biochar; PM = Poultry manure; NPK 15-15-15 fertilizer.

When studied as individual factors, year (Y) has no influence on plant height, number of leaves per plant, root length, root diameter and fresh root yield of carrot. Tillage (T) and fertilizer (F) significantly influenced plant height, number of leaves per plant, root length, root diameter and fresh root yield of carrot. The interactive effects of Y x T and Y x F were not significant for growth and yield parameters. The interactive effects of T x F were significant for number of leaves per plant, root length, root diameter and fresh root yield of carrot, but, not significant for plant height. When all the three factors (Y x T x F) were considered, interactions were not significant for growth and yield parameters.

4. Discussion

The soil of the site of the experiment was low in OC, N, P, K, Ca and Mg, and acidic with high bulk density. These conditions are the characteristics of soils in the humid tropical regions. The high bulk density before the commencement of the experiment was attributed to the low organic matter content and compaction resulting from weak structure of soil in the study area. The low soil nutrient status could be partly related to low organic matter content and low clay content in the soil, and also attributed to the nature and continuous cultivation over the years without addition of manure or fertilizer inputs. Hence, there is dire need for the application of organic amendments or inorganic fertilizer that can improve soil properties, growth and carrot productivity.

The lower soil bulk density and lower penetration resistance, and higher total porosity of reduced tillage compared with conventional tillage might be explained by loosening effects of tillage (Agbede and Adekiya, 2018). The higher soil bulk density, higher penetration resistance, and lower total porosity of conventional tillage compared with

reduced tillage was attributed to wheel traffic of tractor and implement passes which compact the soil. Therefore Alfisols have a coarse texture surface horizon overlying a clayey sub-surface layer which are weak in structure and highly susceptible to crusting, compaction and accelerated erosion under conventional tillage (Adekiya et al., 2011). The higher soil bulk density and higher penetration resistance produced by conventional tillage was due to break down of soil structure due to slaking and rain-drop impacts. Conventional tillage/repetitive tillage degrades soil qualities and causes rapid collapse of soil structure especially under tropical conditions. Reduced tillage had lower bulk density, higher water content and lower temperature compared with conventional tillage. This could be attributed to the presence of organic matter within the top 0–15 cm soil depth, which acted as mulch to reduce temperature and evaporation loss of water. The lower water content of conventional tillage could be attributed to rapid decomposition of organic matter, leading to oxidation, thereby increase temperature and water loss by evaporation.

The reason for the higher mean weight diameter (MWD) and higher aggregate stability values in reduced tillage compared to conventional tillage was due to the high organic carbon content obtained in the reduced tillage (Table 4). Soil organic carbon is the major cementing factor or binding agent in aggregate formation in soil and moreover, according to most researchers, is significantly correlated with aggregate stability (Liu et al., 2019; Zhou et al., 2020). This study agrees with the findings of Acar et al. (2018) who reported that soil aggregates under reduced tillage systems were found more stable than conventional tillage. Similarly, MWD values under reduced tillage were found to be higher than conventional tillage (Celik et al., 2012; Acar et al., 2018). Abdollahi and Munkholm (2014) reported that reduced tillage systems increased MWD values, and water-stable aggregates compared to conventional

tillage. The reason for the lower dispersion ratio values under reduced tillage compared with conventional tillage was attributed to the high organic carbon content obtained in the reduced tillage. The soil surface exposed after intensive tillage is prone to break down of aggregates as the energy from raindrops is dissipated resulting in clogging of soil pores, consequently reducing water infiltration and dispatching of soil particles. Therefore in the sub-humid and humid regions of the tropics, the high intensity rainfall tends to nullify the loosening effect of tillage under intensive/repetitive tillage.

Application of biochar alone, poultry manure alone and mixture of NPK fertilizer, biochar and poultry manure at sub-optimal rates reduced soil bulk density, penetration resistance, dispersion ratio and temperature and increased water content, porosity, aggregate stability and mean weight diameter while NPK fertilizer did not influence any of these soil physical properties (Table 3). The improvement (decrease/increase) observed in these soil physical properties in the biochar alone, poultry manure alone, and mixture of NPK fertilizer, biochar and poultry manure treated plots were significantly higher ($p = 0.05$) than the control and NPK fertilizer. Application of poultry manure has been reported to improve soil physical properties (Agbede et al., 2017; Adekiya et al., 2019). This was attributed to the enhancement of soil organic matter by poultry manure. Application of biochar was reported to improve soil physical properties such as soil structure, bulk density, porosity, texture, and particle size distribution and affects important soil function such as water holding capacity, aeration and plant growth (Atkinson et al., 2010).

The decrease in bulk density and penetration resistance, increase in total porosity and water content in the biochar amended soils was attributed to physical dilution effects (Lehmann et al., 2011; Albuquerque et al., 2014), thorough interaction with soil particles and improving aggregation and porosity (Blanco-Canqui, 2017) and as a result of alteration of soil aggregate sizes, as shown by Duarte et al. (2019), which agrees with the findings of Zhang et al. (2016) who indicated that increasing total organic carbon by the application of organic amendments in soils could significantly decrease bulk density. The reason why the soil aggregate stability increased in the biochar-amended soils compared with the control could be added to its high carbon content (Alghamdi, 2018). The carbon molecules form bonds with the oxides, and the organic matter serves as food for soil microorganisms making the environment favourable for them. The substrates supplied to the microorganisms by the labile organic matter on the surface of biochar enhance the excretion of mucilage by microorganisms, which in turn builds stable soil aggregate. According to Mirzaei Amninyan et al. (2015), organic amendment has been known to enhance soil aggregate formation and stability.

Application of biochar reduced soil temperature because of its intrinsic electrical and thermal properties. This corroborates the findings of Zhang et al. (2013). Mean weight diameter (MWD) indicates prevalence of larger and more stable aggregates and therefore is an index of soil aggregate stability and quality (Le Bissonnais, 2016; Zhou et al., 2020). Mean weight diameter (MWD) of the soil aggregates increased significantly in biochar-amended soils compared with the control, which could be attributed to an increase in the amount of oxidized functional groups after mineralization of the biochar (Wang et al., 2017), thereby facilitated flocculation of both the soil particles and the biochar. The incorporated biochar could function as a binding agent that connects soil micro-aggregates to form macro-aggregates. The oxidized biochar surface, which included hydroxyl groups and carboxylic groups, could adsorb soil particles and clays to form macro-aggregates (Jein and Wang, 2013). Biochar/poultry manure-amended soils reduced dispersion ratio compared with non-treated soils. This was attributed to the organic matter from the biochar/poultry manure incorporated into the soil. The biochar/poultry manure incorporated stabilized the soil structure and reduced dispersion ratio since organic matter addition is essential for stabilizing soil against physical degradation and soil erosion. Soils with high dispersion ratio are weak structurally and can easily be eroded. A

combination of biochar, poultry manure and NPK fertilizer improved soil properties more than biochar alone or poultry manure alone due to more stable organic carbon in biochar in combination with the higher organic matter in poultry manure which resulted in improved soil structure and stable aggregates. For example, biochar combined with poultry manure increased soil aggregation compared with biochar alone as poultry manure has provided labile or transient organic binding agents to bind biochar and inorganic particles into stable aggregates (Khademalrasoul et al., 2014).

Soil under the reduced tillage treatment had higher soil pH, OC, N, P, K, Ca and Mg concentrations at the 0–15 cm depth than that under the conventional tillage treatment due to accumulation of plant residues on the soil surface and their slow degradation. The lower values of soil OC, N, P, K, Ca and Mg recorded for conventional tillage could be related to different processes which include rapid decomposition of plant residues as a result of frequent soil disturbance, inversion of top soil during ploughing which brought less fertile subsoil to the surface in addition to possible leaching, increase in oxidation and mineralization of organic matter. This is consistent with the results of previous studies (Malecka et al., 2012; Zukaitis and Liaudanskiene, 2020). This study showed a 9.6% decrease in soil organic C within the top 0–15 cm soil depth after 2 year of reduced tillage compared to conventional tillage that showed a 17.8% decrease in soil organic C within the top 0–15 cm soil depth after 2 year. In temperate climate, long-term tillage study by Blanco-Canqui et al. (2017) found a 2.6% increase in soil organic C within the top 0–20 cm soil depth after 24 year of no tillage. However, plowed tillage caused 7.1% decrease in soil organic C within the top 0–20 cm soil depth after 24 year (Blanco-Canqui et al., 2017).

Application of biochar and poultry manure increased soil pH, OC, P, K, Ca and Mg concentrations, which is consistent with the analysis recorded for the biochar and poultry manure (Table 2), and also due to their nutrients availability by stimulating microorganisms to mineralize soil organic matter. Application of biochar alone and poultry manure alone increased soil pH compared with the control. This could be attributed to increased availability of organic matter and high concentrations of alkali metals and exchangeable basic cations (Ca, Mg, K and Na) present in the biochar and poultry manure ash fractions which act as liming agents in acidic soils. Apart from the direct release of mineral nutrients, biochar and poultry manure have been shown to increase soil pH and microbial activity (Subedi et al., 2016; Adekiya et al., 2019, 2020). The increases in soil N, P, K, Ca and Mg observed in NPK fertilizer alone compared to the control, could be due to decomposition of organic matter and mineralization of its nutrients. The increases in OC and nutrient concentrations observed in poultry manure-amended soils was attributable to the nutrients release from the poultry manure after decomposition. Poultry manure has been demonstrated to increase soil OC, N, P, K, Ca and Mg (Agbede et al., 2017; Adekiya et al., 2019, 2020). Application of biochar alone increased soil OC, N, P, K, Ca and Mg compared with the control. Mechanisms responsible for increasing plant nutrient availability are increase in soil pH (in acidic soils), nutrient retention (due to increase in cation exchange capacity and surface area) or directly release of nutrients from the biochar surfaces (Clough et al., 2013; DeLuca et al., 2015; Subedi et al., 2016). Biochar has been reported to play an important role in enhancing nutrient retention in soil mostly due to its surface charge density (Kongthod et al., 2015). Biochar has been demonstrated to have negatively charged surfaces which increases the adsorption capacity of cations (Lou et al., 2016).

Combined application of NPK fertilizer, biochar and poultry manure at sub-optimal rates had lower soil pH, organic C and higher soil N, P, K, Ca and Mg compared with biochar alone. The lower soil pH recorded by the mixture of NPK fertilizer, biochar and poultry manure compared with biochar alone was due to the acidic nature of the NPK fertilizer in the mixture which could probably have contributed less in raising the soil pH, while in addition to the increased soil pH by biochar in the combined application of biochar, poultry manure and NPK fertilizer plots, poultry manure also contributed through the complexation of its organic anion

being released into the soil exchange site. The combined application of NPK fertilizer, biochar and poultry manure recorded a lower soil OC than the biochar alone, which could be added to the less or no contribution of the NPK fertilizer to add C input into the soil environment compared to the C input being added by the biochar. Biochar has been reported to sequester OC into the soil (Lehmann and Joseph, 2015). The increase of the OC in the combined application of NPK fertilizer, biochar and poultry manure than the poultry manure alone was due to the additional C added by the biochar and the C from the organic matter through the poultry manure addition whereas the poultry manure alone solely depended on the C input from the poultry manure itself. The combined application of NPK fertilizer, biochar and poultry manure increased soil total N, available P, exchangeable K, Ca and Mg concentrations compared with NPK fertilizer alone, biochar alone and poultry manure alone. This could be partly attributed to increased microbial activities and mineralization of nutrients induced by biochar and poultry manure addition, which should have increased nutrient availability, and the synergistic relationship between the biochar, poultry manure and NPK fertilizer and the higher amount of nutrients in the NPK fertilizer and poultry manure, which could probably result in higher plant nutrients availability and nutrient use efficiency. These findings attest to the positive cumulative effect of NPK fertilizer, biochar and poultry manure on soil productivity.

In this study, it was found that carrot productivity differed between tillage treatments. Fresh root yield of carrot was significantly higher in the reduced tillage treatment than the conventional tillage treatment. This agrees with results of previous studies (Bajkin et al., 2010; Brainard and Noyes, 2012). Growth and fresh root yield of carrot increased with reduced tillage. This could be attributed in part to improving soil physical properties, especially bulk density/porosity and penetration resistance due to loosening effect of tillage. These attributes are known to enhance root penetration and uptake of N, P and especially K that is essential for carrot. Carrot performance is known to be strongly influenced by N and K (Ali et al., 2003). Reduced tillage had been reported to improve soil physical properties, such as bulk density, porosity, penetration resistance, water content, aggregate stability, mean weight diameter, dispersion ratio, root penetration, and water and air permeability (Malicka et al., 2012; Celik et al., 2012; Acar et al., 2018). Also, increased crop residue by reduced tillage has been reported (Shahzad et al., 2019), to keep the soil surface cool and reduce soil temperature and loss of water by evaporation. These effects subsequently leads to increased water use efficiency of the crop (Blanco-Canqui et al., 2017; Obour et al., 2018). The lower growth and fresh root yield of carrot recorded for the conventional tillage treatment is consistent with the deteriorating soil physical properties, especially higher bulk density, higher penetration resistance and lower porosity (soil compaction), and relatively low soil pH, OC, N, P, K, Ca and Mg concentrations recorded for the treatment (conventionally tilled soil).

The best growth and yield performance of carrot observed under complementary use of biochar, poultry manure and NPK fertilizer compared with NPK fertilizer alone, biochar alone or poultry manure alone could be attributed to increased nutrient use efficiency and quality of the nutrients released by these fertilizers (NPK fertilizer/biochar/poultry manure) to the soil solution and whose assimilation by the root of carrots was favourable to the growth and therefore to production yield. This was associated with better improvement in physical properties (Table 3) and higher soil N, P, K, Ca and Mg concentrations (Table 4) given by the treatment. This agrees with the findings of Agegnehu et al. (2016) and Subedi et al. (2016) that high and sustained crop yield could be achieved with a judicious and balanced NPK fertilizer combined with organic matter amendments. Indeed, biochar and poultry manure addition provides essential nutrients to plants and thus serve as soil amendments by adding organic matter that improves nutrient retention while NPK fertilizer provides most of the chemical compound needed for quick growth and development of the carrot crop. As most biochars derived from wood biomasses, with the exception of manure are poor in nutrient

compositions, studies have shown that biochar affect positively on crop growth and yield when applied in combination with fertilizers i.e. organic as well as inorganic (Subedi et al., 2015; Agegnehu et al., 2016). This is probably due to the positive interaction between biochar, poultry manure and applied fertilizer that improved the availability of nutrients associated with enhanced plant uptake and reduced losses of these nutrients. Study by Schmidt et al. (2015) reported an 85% increase in pumpkin crop yield versus the control following soil application of *Eupatorium* weed-derived biochar. The yield rose to 300% when cattle urine was added to this biochar before soil application. Agegnehu et al. (2016) found that compost or compost + biochar with N fertilizer increased barley grain yield up to 60% compared to the yield with the highest N fertilizer alone. Similar yield increases have been reported by Xiao et al. (2016) in maize, Kammann et al. (2015) in *Chenopodium*, and Albuquerque et al. (2013) in wheat when biochar was combined with either organic residues/compost or mineral fertilizer, and indicate that wood biochar may enhance nutrient use efficiency when added to organic/inorganic fertilizer/crop residues. The significant interaction observed between tillage and fertilizer on soil physical properties, OC, N, K, Ca and Mg, number of leaves per plant, root length, root diameter and root yield of carrot indicated that both factors must be carried out simultaneously in order to realize optimum benefits. These findings revealed that the effects of tillage are compensated by fertilization while nutrients in the fertilizer are uptake by plants through soil loosening created by tillage.

5. Conclusions

The results of this study revealed that reduced tillage improved the physical characteristics of the soil as well as the soil chemical properties, and therefore resulted in increased growth and yield of carrot more than the conventional tillage. Combined application of NPK fertilizer, biochar and poultry manure at sub-optimal rates with any tillage method ensured more improvement in soil physical properties, availability of major nutrients in soil and increased growth and carrot root yield compared with full rates of NPK fertilizer, biochar or poultry manure alone. Biochar, poultry manure or NPK fertilizer increased soil fertility, growth and carrot root yield compared with the control, but soil conditions, especially physical properties were better in biochar and poultry manure than NPK fertilizer. Reduced tillage in combination with NPK fertilizer plus biochar plus poultry manure gave the best improvement in soil properties as well as highest carrot root yield and therefore recommended as an emerging climate smart agronomic package for carrot production in the rainforest agroecology of southwest Nigeria. However, more research is needed on different soil types and different agro-ecosystems beyond two years.

Declarations

Author contribution statement

Taiwo Michael Agbede: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Additional information

No additional information is available for this paper.

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